OTC 15348

Prediction of TLP Responses: Model Tests vs. Analysis

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Abstract

This paper presents an overview of prediction of TLP responses: model tests vs. analysis, sponsored by DeepStar Phase V program. ABB and Marintek were invited to carry out the task, which was intended to provide an overall assessment of the current capabilities of the industry in predicting TLP responses and highlight areas of uncertainties and sensitivities.

The paper summarizes key results of TLP responses in 6,000 ft water depth of Gluf of Mexico field. Non-linear coupled dynamic analyses were employed indenpently by both ABB and Marintek to model the system in a consistent and accurate manner. The measured hull, tendon and riser configurations, as well as the measured wave elevations, wind loads and mean current velocity profile were applied. The overall correlations between model tests and analyses demonstrated the industry has the analytical capability in predicting the TLP responses. However, analytical tools are not perfect and physical model test is still an important design tool to verify the analyses.

Introduction

The DeepStar Program sponsored a series of tasks to evaluate the current industry capability in predicting the responses of deepwater theme structures (FPSO, TLP and SPAR). In its Phase IV program, model tests of the FPSO, TLP and SPAR were conducted, and in the Phase V program, engineering companies as well as test basins were invited to evaluate the correlations between the tests and analyses.

The TLP physical model tests were carried out in MARIN wave basin tank in January 2001 in water depth of 6,000 feet under Gulf of Mexico hurricane and loop-current conditions. The details of test setups, wave, wind and current generations and cablibrations were described in paper OTC 15346 (ref. 1).

In deep or ultra deepwater, the TLP platform tends to interact more pronouncedly to its tendons and risers. The dynamic interactions among platform, tendons and risers cannot be evaluated accurately and consistently by using the conventional uncoupled analysis tools, where the platform, tendons and risers are treated separately. Therefore, analytical capability of fully coupled dynamic analyses was required to complete the project. Both ABB and Marintek performed fully coupled dynamic analyses indenpenly by their own softwares. The purpose of this excerise is to investigate whether the existing numerical tool applying the measured data could reproduce the measured results and identify the gaps for further study.

This paper presents an overview of both ABB's and Marintek's work. It includs the following aspects of the study:

- Model test setup and environmental criteria
- The state-of-art analytical tools available to the industry
- Key results of comparisons – tests vs analyses
- Sensitivities and uncertainties in predicting TLP responses
- Assessment of current industry capabilities
- Areas of future efforts

Model Test Setup

TLP hull, tendon and riser configurations, tendon numbering, both tendon and riser locations, tendon porch elevation and riser top elevations were illustrated in Figure 1.

- **Hull Configuration**
  Hull configuration, measured hull weight, tendon top tensions and riser top tensions were given in Table 1.
- **Tendon Configuration**
  Tendon configuration, measured tendon dry weight and wet weight were summarized in Table 2.
- **Riser Configuration**
  Riser configuration, measured riser dry weight and wet weight were documented in Table 3.
- **Definition of Wave Heading and Coordinate**
  Definitions of wave heading and platform coordinate were shown in Figure 2.

Environmental Criteria and Case Descriptions

Environmental criteria specified by DeepStar CTR 4401B were summarized in Table 4 and Directions are shown in Figure 3.

The cases specified by DeepStar (ref. 2) for theme structure TLP study are 100-year hurricane, wave only, 100-year hurricane wave/wind/current (WWC) and 100-year loop current, wave/wind/current (WWC). All cases are focused on seed 1. Since 100-year hurricane, wave only case was mainly for identifying wave effects, which was not real case for design, therefore 100-year hurricane WWC and 100-year loop current WWC were two major extreme cases to be focused on in this paper. The time intervals and seed number of these two sea states for comparisons were summarized in Table 5.

Numerical Model

The detailed physical model of the TLP, tendons and risers were described in the MARIN report (ref. 3). The principle data were extracted from the report and reproduced in Tables 1, 2 and 3.

- **Software Description**
  Both ABB and Marintek employed fully coupled dyamic analysis software. ABB used Multi_Cat, for which the methodology and parameter studies of TLP and classical SPAR have been presented in ref. 4 and analysis capability has been further extended to include applying measured wave elevation and wind loads. The new program was named as Multi_Cat. Marintek employed the program system RIFLEX-C (ref. 5), composed of a sequential run of RIFLEX (ref. 6) and SIMO (ref. 7). Hydrodynamic vessel coefficients from linear and second-order potential theory are obtained by use of the diffraction-radiation program WAMIT (ref. 8). A more detailed study on the fully coupled TLP modeling by MARINTEK is presented in Ref. 11.
- **TLP Hull Model**
  The majority of the TLP hull hydrodynamic coefficients were established by use of WAMIT. The panel model of the submerged body of the hull was shown in Figure 4 (ref. 9). Total 9080 panels were utilized to discribed the hull and symmetry conditions were imposed.
  Both ABB and Marintek considered complete second-order diffraction theory. In addition to the hull mesh, the free surface has to be discretized. The panel mesh of the free surface is shown in Figure 5 (ref. 9). Total 7392 panels were used, the radius of the discretized area (PARTR) is 96 m and symmetry conditions are imposed.
  Since the diffraction theory ignores viscous effects, viscous loads on the TLP hull are computed by Morison's equation.
- **Tendons and Risers**
  Tendons and risers are slender members, which were discrized by FE bar elements without bending and torsional stiffness. Wave and current loads on these small diameter members can be computed by Morison's equation. Viscous effects, mass and added mass of slender members are included in the governing equations. Dynamic responses of tendon and riser were simulated, which were not based on quasi-static approach.
- **Environment Modeling**
  Environment exciting loads due to wave, wind and current are considered in this study. The measured irregular wave elevation time series were employed in simulations. The measured horizontal wind loads at the pressure center were applied in ABB's analyses. However Marintek adjusted wind coefficients to take into account slight non-omnidirectional effect (increase in oblique wind, as seen from wind tests), and then reduced by 10%. No measured wind yaw moment was provided by wave basin. Therefore wind induced yaw motion was not simulated. The current was modelled steady in time (no fluctuations), with the specified vertical profile. Both ABB and Marintek considered wave, wind and current non-colinear. The headings of wave, wind and current in 100-year hurricane WWC and 100-year loop current WWC were shown in Figure 3.
- **Coupling Modeling**
  The complete system is analysed by a coupled analysis approach; i.e. the TLP force model is introduced as a nodal load component in a Finite Element (FE) model of tendons and risers. Among TLP hull and tendons or risers, forces are exchanged back and forth. It should be noted that this approach yields dynamic equilibrium between the forces acting on the TLP and tendons and/or risers at every time instant.
- **Convergence Tests**
  Convergence tests have been carried out to ensure meaningful numerical results prior to extensive runs. Two aspects of convergence tests have been performed: one is to check mesh size on body and free surface to secure hydrodynamic loads, specially sum-frequency loads, converged and the other is to examine number of finite elements of tendons and risers sufficient for dynamic line tensions to converge.

Key Result Comparisons

Calibrated analysis results by Marintek (ref. 9) and initinal analysis results by ABB (ref. 10) were employed to carry out comparisons, measured vs. simulated. In ABB's simulation results, only drilling riser tensions were based on sensitivity analysis by adjusting drag coefficient Cd on drilling riser. In Marintek's simulation results, a few adjustments were made based on initinal comparisons between dynamic simulations and model tests in irregular waves, current & wind. The main adjustments were summarized as follows:

- Pre-tension increased 5% from the reported tension.
- Slightly adjusted axial tendon & riser stiffnesses to better match HF tension spectra
- Viscous forces on slender components:
  C_D of tendons increased from 1.0 to 1.1, C_D of risers increased from 1.0 to 1.2.
- LF pitch drift moment included: Drift coefficients (QTF diagonal) are found from the linear WAMIT model, and empirically multiplied by 3 to take into account off-diagonal effects
- Additional linear springing damping: 7% of critical had to be added to match measurements, giving a total level of 10%. This might be due to PVC material used in tendon models.

- Wind coefficients adjusted to take into account slight non-omnidirectional effect (increase in oblique wind, as seen from wind tests), and then reduced by 10%.

Both Marintek and ABB have carried out very extensive studies (ref. 9 and ref. 10). Only a few key results are extracted and presented in this paper.

Static Offset, Setdown and Tendon Tension

In order to verify the physical and numerical setup, static offset tests have been carried out. Static offset and setdown comparisons of the measured and simulated are showed in Figures 6 and 7. It is seen that the measured and simulated (both ABB and Marintek) agree well.

Comparisons of the measured and simulated static up-wave and down-wave tendon tension are shown in Figures 8 and 9. It is seen that the measured and simulated (both ABB and Marintek) agree well.

Free Decay

The six-degree-freedom free decay tests have been performed and results are summarized in Table 6. Since the measured axial stiffness was softer than the target value, Marintek made adjustments to match the measured data after initial comparisons while ABB hasn't maken any adjustment just as test specification defined.

Motion Response Comparisons

- ***Surge/Sway Motions in 100-year Hurricane WWC***

Surge/sway motions in 100-year hurricane, wave, wind and current are summarized in Tables 7 and 8 and their amplitude spectra are showed in Figures 10 and 11. Form Table 7, it is seen that the measured and simulated mean, standard deviation and extreme agree well, which are also showed in Figure 10. From Table 8, it is noticed that the measured sway standard deviation is significantly larger than those of the simulated in term of the percentage. From Figure 11, it is clear that the main differences come from the low-frequency compoent. It has been showed in Figure 3, only wind and current components exist in sway direction. Since the measured wind load time series have been applied, therefore the low-frequency current fluctuation is believed to be the major contributor to the differences.

- ***Surge/Sway Motions in 100-year Loop Current WWC***

Surge/sway motions in 100-year loop current, wave, wind and current are summarized in Tables 9 and 10 and their amplitude spectra are showed in Figures 12 and 13. Form Table 9, it is seen that the measured and simulated mean and extreme agree well (mean dominant) while standard deviation of the measured is about 10 times of those simulated. From Figure 3, it is noticed that only current is in platform East (surge) direction. From Figure 12, it is clear that differences of low-frequency components are dominant sources, which are attributed to the large low-frequency current fluctuations. From Table 10, it is noticed that the measured sway mean and extreme are smaller than those of the simulated while standard deviation of the measured sway is larger than those of the simulated by Marintek. From Figure 13, it is clear that good agreements have been achieved between the measuredt and simulated wave-frequency sway responses while the measured low-frequency components are larger than those of the simulated. It is also noticed that there is a peak around 0.1 rad/sec (about 63 seconds) in the measured sway motion amplitude spectrum. Sharp Peak around 0.1 rad/s is also observed in up-wave and down-wave tendon tension amplitude spectra (Figures 15 and 17) but not in drilling riser tension amplitude spectrum (Figure 19). Since the peak period fits with predictions given by the Strouhal number of column, therefore sharp peak seems to be induced by vortex shedding from the TLP columns in the strong loop current condition. It is not concluded yet since only very limited information is available and further investigations are recommended.

Tendon and Riser Tension Response Comparisons

- ***Up-Wave Tendon Tensions in 100-year Hurricane WWC and 100-year Loop Current WWC***

Up-wave tendon tensions in 100-year hurricane WWC and 100-year loop current are summarized in Tables 11 and 12 and their amplitude spectra are showed in Figures 14 and 15. Form Table 11, it is seen that the measured and simulated tension standard deviation (total) by Marintek agree well while simulated tension standard deviation by ABB is significantly larger than that of the measured. From Figure 14, it is found that Marintek's low-frequency tensions (say, less than 0.2 rad/s) and high-frequency tensions (say, higher than 1.25 rad/s) are slightly smaller than those of the measured respectively, while wave-frequency tensions (say, between 0.2 and 1.25 rad/s) are overpredicted. In ABB's simulation, low-frequency tensions agree well; high-frequency tensions are slightly overpredicted and high-frequency tension peak shifted since axial stiffness has not been adjusted; wave-frequency tensions are significantly overpredicted. It has been observed in the past TLP physical model tests in 3,000 ft, 4,000 ft and 5,000 ft water depths. It seems that trend is the deeper water depth, the more overpredicted tension. It is believed that ratio of tendon mass over platform mass varied with water depth is one of key factors. Further investigations are recommended.

For the TLP design, maximum tendon tension at top and minimum tendon tension at bottom are important for tendon strength and TLP sizing respectively. In the design point of view, higher maximum top tension and lower minimum bottom tension are on the conversative side. From Table 11, it is noticed that the simulated maximum and minimun tensions by ABB are higher and lower than those of the measured respectively, which are conversative for design. Similar trends are also found in Table 12.

From Table 12, it seems to be in good agreements between the measured and simulated of tension standard deviation. However, the distributions of the low-, wave- and high-frequency tensions of the measured and simulated are different as showed in Figure 15. In the loop current WWC, the high-frequency tensions of the measured and simulated agree well; the wave-frequency tensions of the simulated are larger than those of the measured as usual;

the low-frequency tensions of the measured are significantly lower than those of the measured, which are attributed to the strong low-frequency current fluctuations, possible of VIV on tensons and hull.

- ***Down-Wave Tendon Tensions in 100-year Hurricane WWC and 100-year Loop Current WWC***

Down-wave tendon tensions in 100-year hurricane WWC and 100-year loop current are summarized in Tables 13 and 14 and their amplitude spectra are showed in Figures 16 and 17. Form Table 13, it is seen that the simulated tension standard deviation (total) by Marintek is lower than that of the measured while simulated tension standard deviation by ABB is larger than that of the measured. From Figure 16, it is found that Marintek's and ABB's low-frequency tensions are higher than those of the measured considerably, while ABB's wave-frequency tensions agree well and Marintek's wave-frequency tensions are significantly underemtimated. In ABB's simulation, high-frequency tensions are overpredicted and high-frequency tension peak shifted since axial stiffness has not been adjusted; Marintek's high-frequency tensions agree well with those of the measured.

From Table 13, it is noticed that the simulated maximum and minimun tensions by ABB are slightly lower and higher than those of the measured respectively, which imply the 3-hour tension extreme factors of down-wave tendon are higher than those of the simulated.

From Table 14, it seems to be in good agreements between the measured and simulated of tension standard deviation. However, the distributions of the low-, wave- and high-frequency tensions of the measured and simulated are different as showed in Figure 15. In the loop current WWC, the high-frequency tensions of the measured and simulated agree well; the wave-frequency tensions of the simulated are larger than those of the measured as usual; the low-frequency tensions of the measured are significantly lower than those of the measured, which are attributed to the strong low-frequency current fluctuations, possible of VIV on tensons and hull.

- ***Drilling Riser Tendon Tensions in 100-year Hurricane WWC and 100-year Loop Current WWC***

Drilling riser tensions in 100-year hurricane WWC and 100-year loop current are summarized in Tables 15 and 16 and their amplitude spectra are showed in Figures 18 and 19. Form Table 15, it is seen that the simulated tension standard deviations (total) by Marintek and ABB are lower than that of the measured. From Figure 18, it is found that Marintek's and ABB's low-frequency tensions are slightly lower than those of the measured, while the simulated wave-frequency tensions are lower than those of the measured.

From Table 15, it is noticed that the simulated maximum and minimun tensions by ABB are slightly lower and higher than those of the measured respectively, which are not conversative for design.

From Table 16, it is found that the drilling riser tension standard deviation of the measured is considerably higher than those of the simulated. From Figure 19, it is clear that the measured low-frequency tensions are significantly higher than those of the simulated while the measured and simulated wave-frequency tensions agree well. It is interesting to point out that there is no any peak around 0.1 rad/s as seen in sway motion, up-wave and down-wave tension amplitude spectra (Figures 13, 15 and 17) in the loop current WWC. Large measured low-frequency tensions might be attributed to the strong low-frequency current fluctuations and possible of VIV on risers.

- ***Time Series of Down-wave Tendon Tensions and Drilling Riser Tensions in 100-year Hurricane WWC***

Based on ref. 2, the time intervals and seed number of two sea states for comparisons of the measured and simulated time series are given in Table 5. Only down-wave tendon tension and drilling riser tension in 100-year hurricane WWC are selected. From Figures 20 and 21, it is found that fairly good agreements have been reached between the measured and the simulated (ABB) in terms of the magnitude and phase.

Sensitivity Analysis

- ***Cd Variation***

Based on DeepStar subcommittee's suggestation, ABB has carried out study on influences of Cd variations (±20%) on TLP responses. The detail results are documented in ref 12. Drag coefficient Cd increasing or reducing 20% means Cds of hull, tendons and risers increase or reduce 20% simultaneously. Since the system surge/sway damping is very high, influences of Cd variations on TLP offsets are mainly on the means. Simularly, influences of Cd variations on TLP tendon tensions and riser tensions are also mainly on the means. The simulated mean drilling riser tension could be matched well with the measured by increasing Cd on drilling riser from 1.2 to 1.65 in 100-year hurricane and 1.2 to 1.85 in 100-year loop current. But the simulated standard deviation in 100-year loop current condition is significantly lower than that of the measured. Since VIV might occur in 100-year loop current, while VIV was not included in the numerical simulations.

- ***Wave Drift Damping***

Since the system surge/sway motions are heavely dampened, it is believed that no significant benefit will be gained if wave drift damping were considered in the numerical simulations.

- ***Non-hydrodynamic Damping Effects on Tendon "Springing" Response***

Non-hydrodynamic damping, such as structure damping of tendons and risers and foundation damping of tendons and risers, is part of the real system. These dampings are difficult to quantify. As found in ref. 10, the less damping, the higher high-frequency tendon tensions. It is believed that tendon "Springing" will be weaker if non-hydrodynamic damping included.

Summary and Conclusion

In this study, the detail measured and simulated result comparisons including statistical and spectra comparisons of TLP responses are given in 100-year hurricane WWC and 100-year loop current WWC conditions. The sensitivity analyses (ABB) have been performed. The main conclusions are summarized as follows:

Motion Responses

- In general, as showed before, current industry has capabilities to simulate surge/sway motions fairly accurate in terms of total, mean, low- and wave-frequency components by model the model. However, there exist some uncertainities, for example, in 100-year loop current WWC. Strong low-frequency current fluctuactions induce much larger low-frequency surge motions in which are not noticed in the numerical simulations by applying measured steady current velocity profiles.
- Surge/sway damping is very high in all conditions, due to viscous forces on hull and deep water tendons/risers. It is believed that no significant benefit will be gained if wave drift damping were considered in the numerical simulations. Influences of Cd variations on TLP offsets are mainly on the means.
- Large peak is found in the measured sway motions in 100-year loop current WWC. The peak period is around 63 seconds. Since the peak period fits with predictions given by the Strouhal number of column, therefore sharp peak seems to be induced by vortex shedding from the TLP columns in the strong loop current condition. It is not concluded yet since only very limited information is available and further investigations are recommended.

Tension Responses

- In general, as discussed before, current industry has abilities to simulate tendon and riser tensions fairly accurate in terms of total, mean, low-, wave- and high-frequency components by model the model. However, there exist some uncertainities, e.g. in 100-year loop current WWC, the measured low-frequency tensions are considerably higher than those of the simulated in both up-wave and down-wave tendon tensions.
- Springing oscillations are reasonably well repoduced in spectra, but not always identical in the time domain. Springing is not negligible, even with the high heave damping in model tests (PVC material). Tendon springing responses are very important for tendon fatigue life estimation, dampings of heave, roll and pitch should be dealed with very carefully for simulating tendon springing responses.
- The simulated wave-frequency standard deviation tension of the up-wave tendon is significantly higher than that of the measured. This phenomenon has been found in other deepwater TLP model tests. But none of them is so pronounced. It is believed that ratio of tendon mass over platform mass varied with water depth is one of key factors. Further investigations are recommended.
- Simularly as found in the measured sway amplitude spectrum, large peak is also found at the same frequency in the measured up-wave and down-wave tendon tension amplitude spectra but not in the measured drilling riser tension amplitude spectrum in 100-year loop current WWC. To identify mechanism, further investigations are recommended.
- As showed before, the measured low-frequency standard deviation of drilling riser tensions are considerably larger than those of the simulated in 100-year loop current WWC, which might imply VIV has occurred in 100-year loop current condition. VIV was not considered in the numerical simulations. Besides, strong low-frequency current fluctuations were also not modeled in the numerical simulations. Further investigations are recommended.

Acknowledgement

The authors are grateful to the management of DeepStar, DNV, ABB and Marintek for their permission and encouragement in the writing of this paper. The authors would like to thank Mr. Edward Huang and Mr. John Chianis (ABB) for reviewing the paper and for their constructive suggestions, and Rolf Baarholm (MARINTEK) for valuable contributions in the numerical analysis.

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TLP Hull	Unit	
Draft	M	31.39
Displacement	Mt	53,392
Column freeboard	M	21.95
Column span c/c	M	60.96
Column diameter (OD)	M	19.51
Column height	M	53.34
Pontoon width	M	9.75
Pontoon height	M	8.53
Deck dimension (NS*EW)	M	79.2X79.2
Deck height	M	13.72
Deck post ht above column	M	2.44
Total weight	Mt	35,633
Tendon pretension @ top	Mt	13,514
Prod.+ drilling riser tension	Mt	4,446

Table 1 TLP Hull Configuration

TLP Tendons	Unit	Measured
Number of tendons		12
Length	M	1,798.72
Diameter (O.D.)	mm	1,044
Total tendon weight (dry)	Mt	13,661
Total tendon weight (wet)	Mt	5,045

Table 2 TLP Tendon Configuration

TLP Risers	Unit	
Number of drilling riser		1
Number of prod. risers		11
Length	M	1867.1
Dia. of drilling riser (O.D.)	mm	522
Dia. of prod. riser (O.D.)	mm	261
Total riser weight (dry)	Mt	5,451
Total riser weight (wet)	Mt	4,235

Table 3 TLP Riser Configuration

Design Cases		100-year Hurricane	100-year Loop Current
Wave Spectrum		Jonswap	Jonswap
Significant wave ht	(ft)	40.0	20.0
Peak Period (Tp)	(sec)	14.0	11.0
Current		Normal	Loop Current
Surface current vel.	(ft/s)	3.5	7.0
Wind Spectrum		API	API
Hourly wind @ 33 ft	(ft/s)	134.9	73.3

Table 4 Metocean Criteria

100-year Hurricane WWC		100-year Loop Current WWC	
Seed	500 s Interval	Seed	500 s Interval
1	2.5 Hr, 1100-1600 s	1	2.5 Hr, 1000–1500 s

Table 5 Time Intervals and Seed Number for Comparisons

Items	Natural Period Comparisons			
	MARIN	MARINTEK		ABB
	Measured	Simulated	Simulated	Simulated
Adjustment	-	No	Yes	No
Heave (sec)	3.9	3.9	3.9	3.5
Pitch (sec)	4.0	4.0	4.1	3.4
Surge (sec)	225.0	225.0	225.0	233.0

Table 6

Items	Surge Motion in 100-yr Hurricane WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (m)	-112	-114.8	-2.8	-112.2	-0.2
Stdev (m)	6.1	4.89	-1.2	6.4	0.3
Extreme (m)	-135	-129.4	5.6	-135.9	-0.9

Table 7

Items	Sway Motion in 100-yr Hurricane WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (m)	-9.8	-9.87	-0.1	-11.9	-2.1
Stdev (m)	3.9	2.04	-1.9	2.15	-1.8
Extreme (m)	-22.1	-16.5	5.6	-20.02	2.1

Table 8

Items	Surge Motion in 100-yr Loop Current WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (m)	143.1	140.6	-2.5	141.5	-1.6
Stdev (m)	3.06	0.24	-2.8	0.32	-2.7
Extreme (m)	149.8	142	-7.8	142.5	-7.3

Table 9

Items	Sway Motion in 100-yr Loop Current WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (m)	13	18.7	5.7	16.2	3.2
Stdev (m)	2.9	1.8	-1.1	2.8	-0.1
Extreme (m)	22.45	26.3	3.9	25.9	3.5

Table 10

Items	Up-wave (#3) Tension in 100-yr Hurricane WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (KN)	15091	15472	381	14577	-514
Stdev (KN)	647	667	20	946	299
Max @ top (KN)	18565	18305	-260	18691	126
Min @ bottom (KN)	8551	9221	670	6377	-2174

Table 11

Items	Up-wave (#7) Tension in 100-yr Loop Current WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (KN)	15535	15888	353	15366	-169
Stdev (KN)	351	255	-96	370	19
Max @ top (KN)	16864	17107	243	16878	14
Min @ bottom (KN)	9550	10696	1146	9527	-23

Table 12

Items	Down-wave (#9) Tension in 100-yr Hurricane WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (KN)	12907	12958	51	12661	-246
Stdev (KN)	903	755	-148	1130	227
Max @ top (KN)	18307	15849	-2458	17817	-490
Min @ bottom (KN)	2680	5810	3130	3018	338

Table 13

Items	Down-wave (#12) Tension in 100-yr Loop Current WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (KN)	15468	15343	-125	15066	-402
Stdev (KN)	475	442	-33	514	39
Max @ top (KN)	17333	17039	-294	16870	-463
Min @ bottom (KN)	9319	8798	-521	8677	-642

Table 14

Items	Drilling Riser Tension in 100-yr Hurricane WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (KN)	8576	8542	-34	8481	-95
Stdev (KN)	329	236	-93	249	-80
Max @ top (KN)	9762	9313	-449	9688	-74
Min @ bottom (KN)	1415	2075	660	1704	289

Table 15

Items	Drilling Riser Tension in 100-yr Loop Current WWC				
	MARIN	MARINTEK		ABB	
	A	B	(B-A)	C	(C-A)
Mean (KN)	9472	9407	-65	9412	-60
Stdev (KN)	143	81	-62	88	-55
Max @ top (KN)	9934	9791	-143	9729	-205
Min @ bottom (KN)	3294	3527	233	3192	-102

Table 16

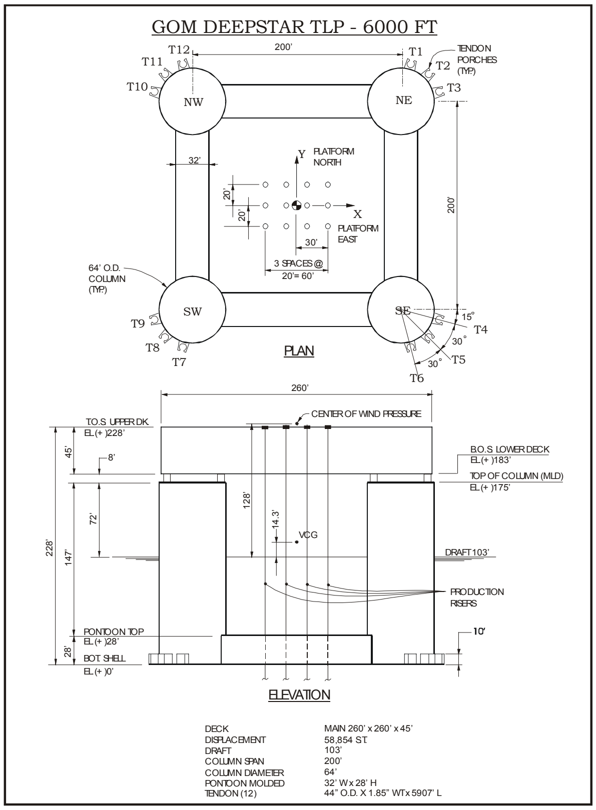

Figure 1 TLP Hull Configuration

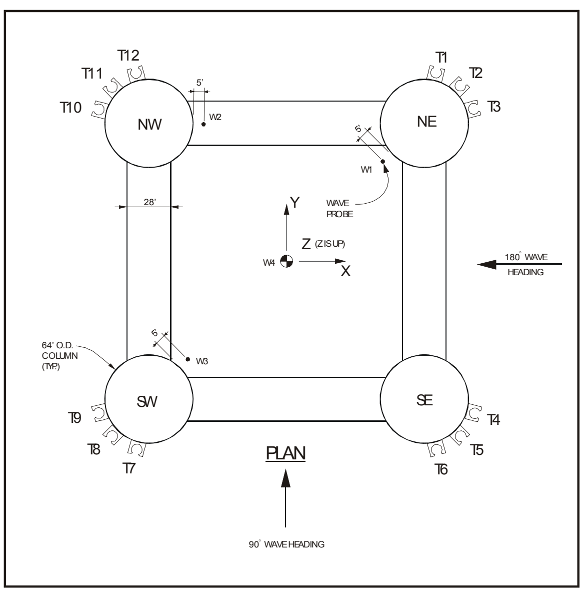

Figure 2 Wave Heading and Coorindate Definition

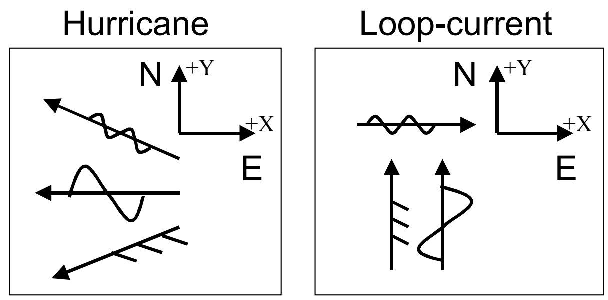

Figure 3 Wave, Wind and Current Directions in 100-year Hurricane WWC and 100-year Loop Current WWC

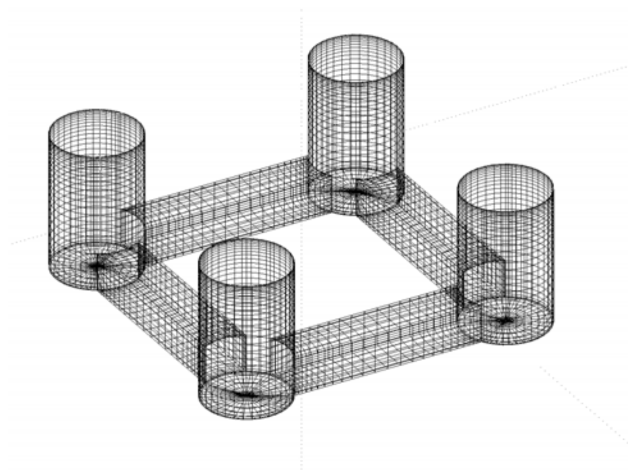

Figure 4 3-D Diffraction Hull Panel Model

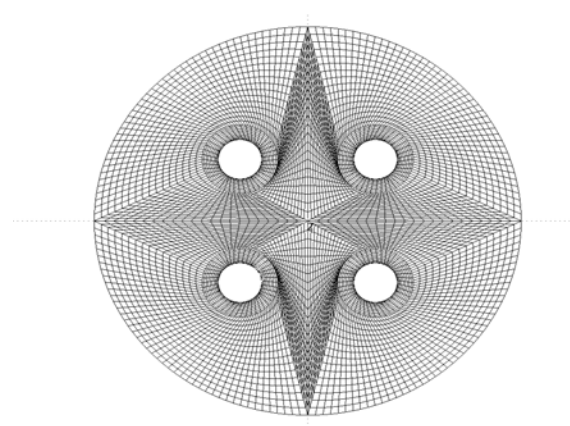

Figure 5 Free Surface Panel Model

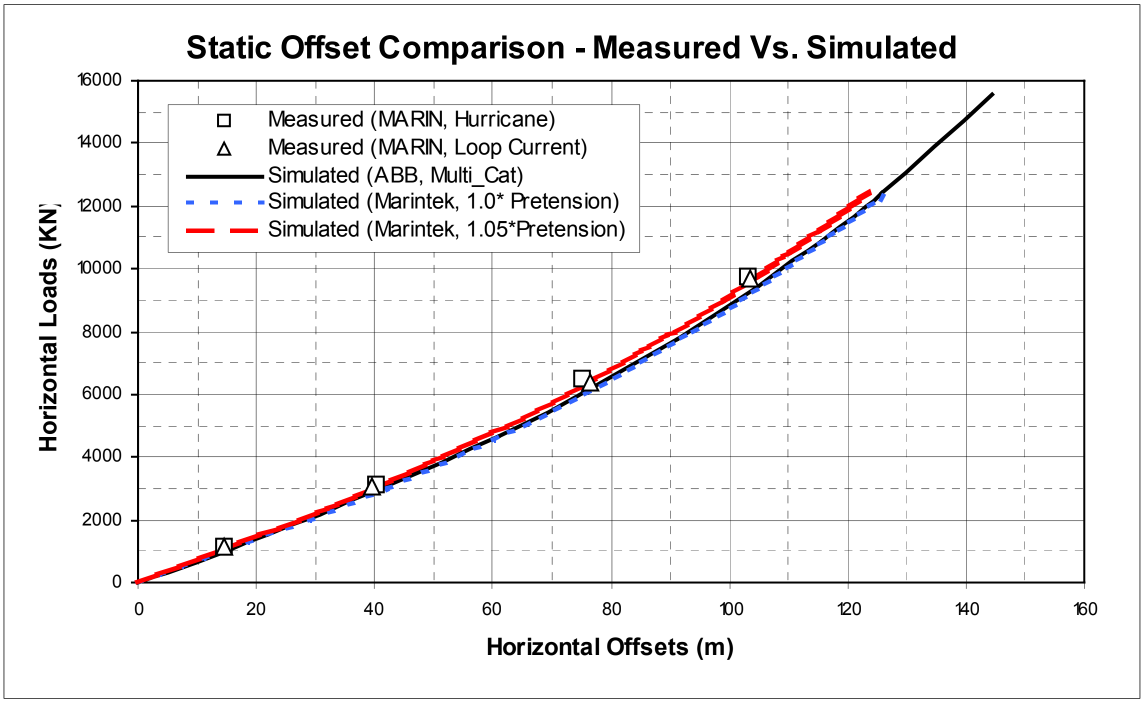

Figure 6

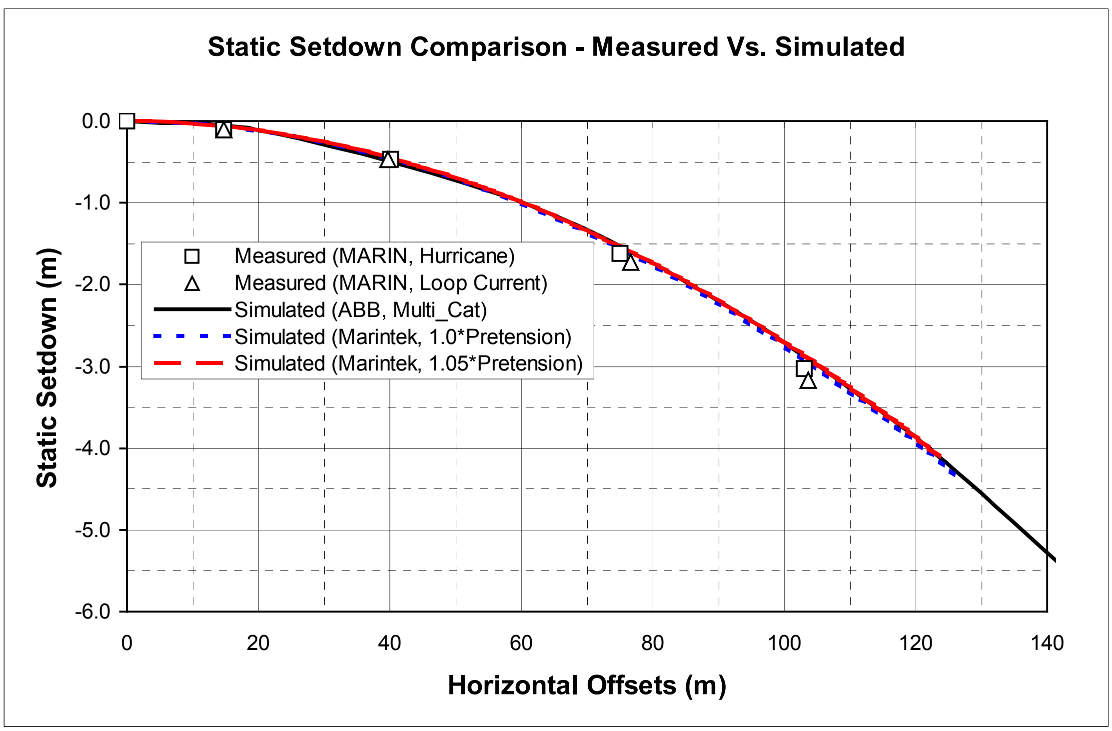

Figure 7

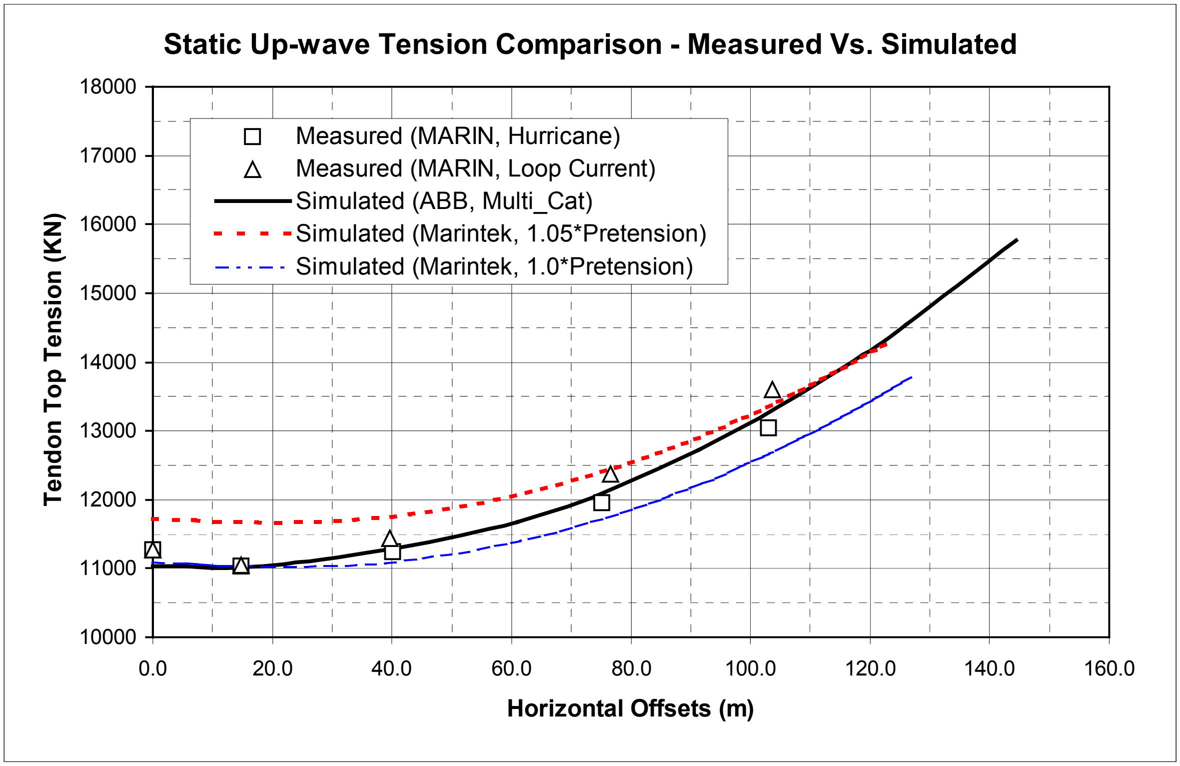

Figure 8

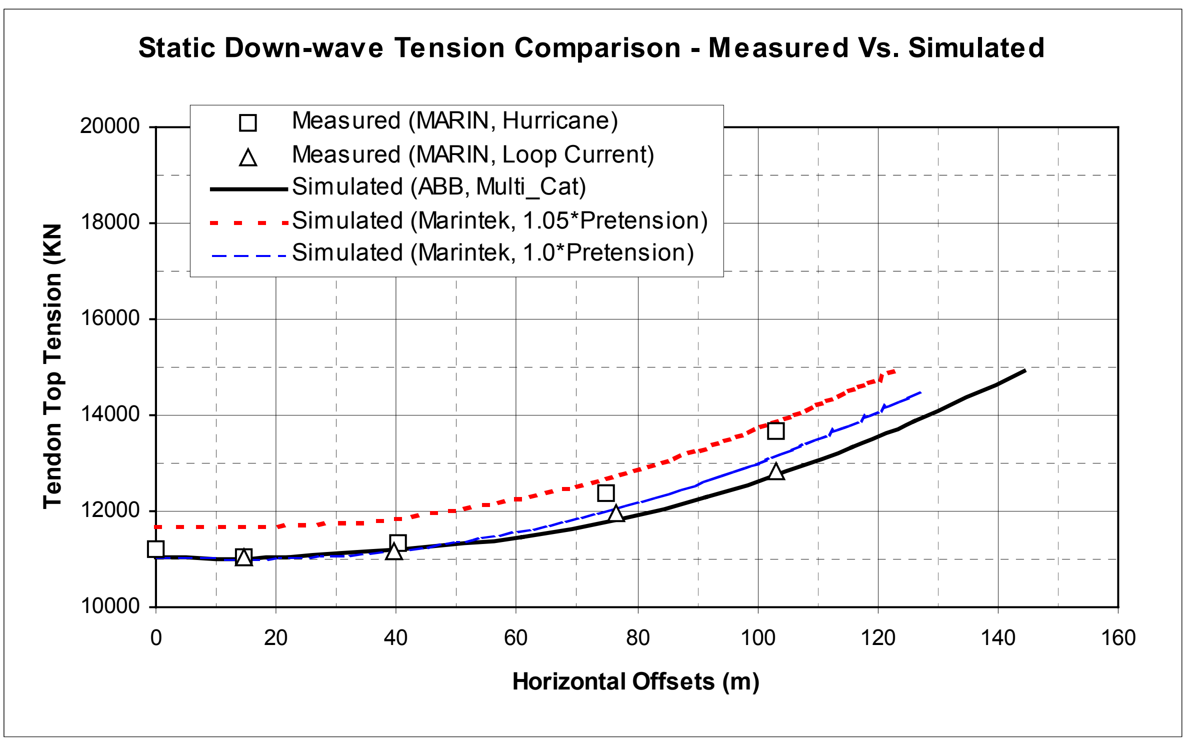

Figure 9

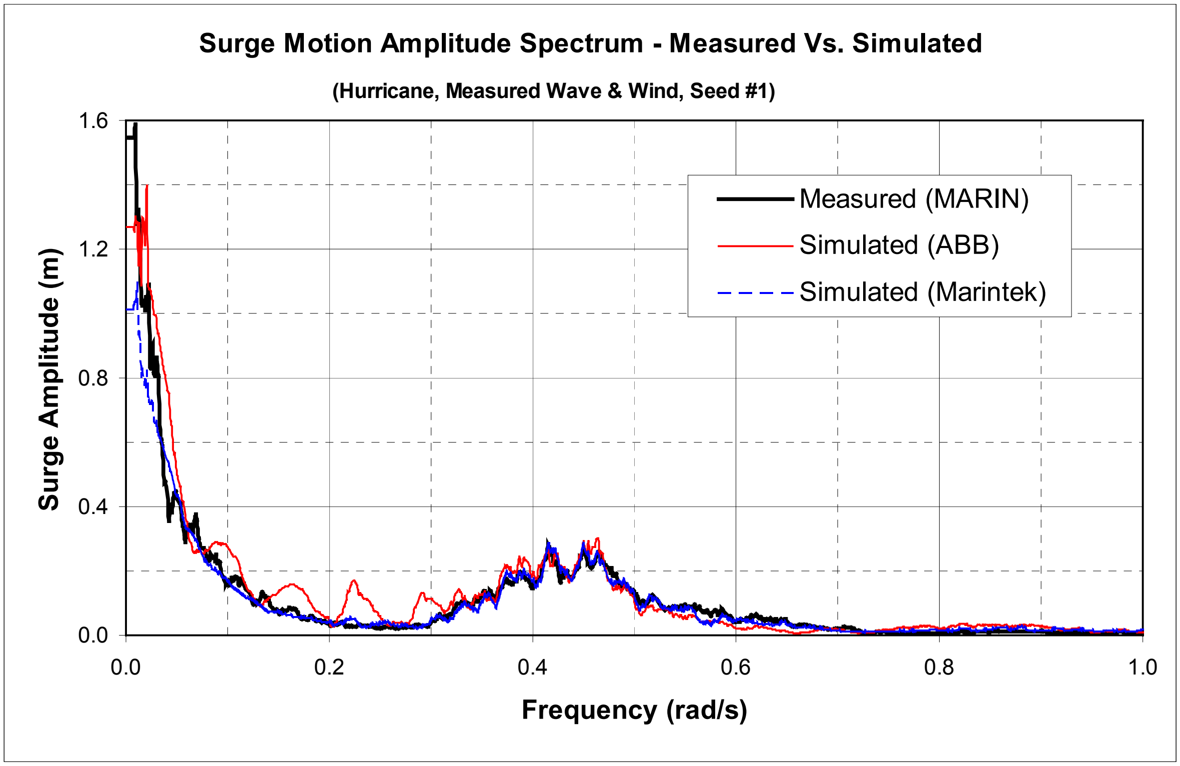

Figure 10

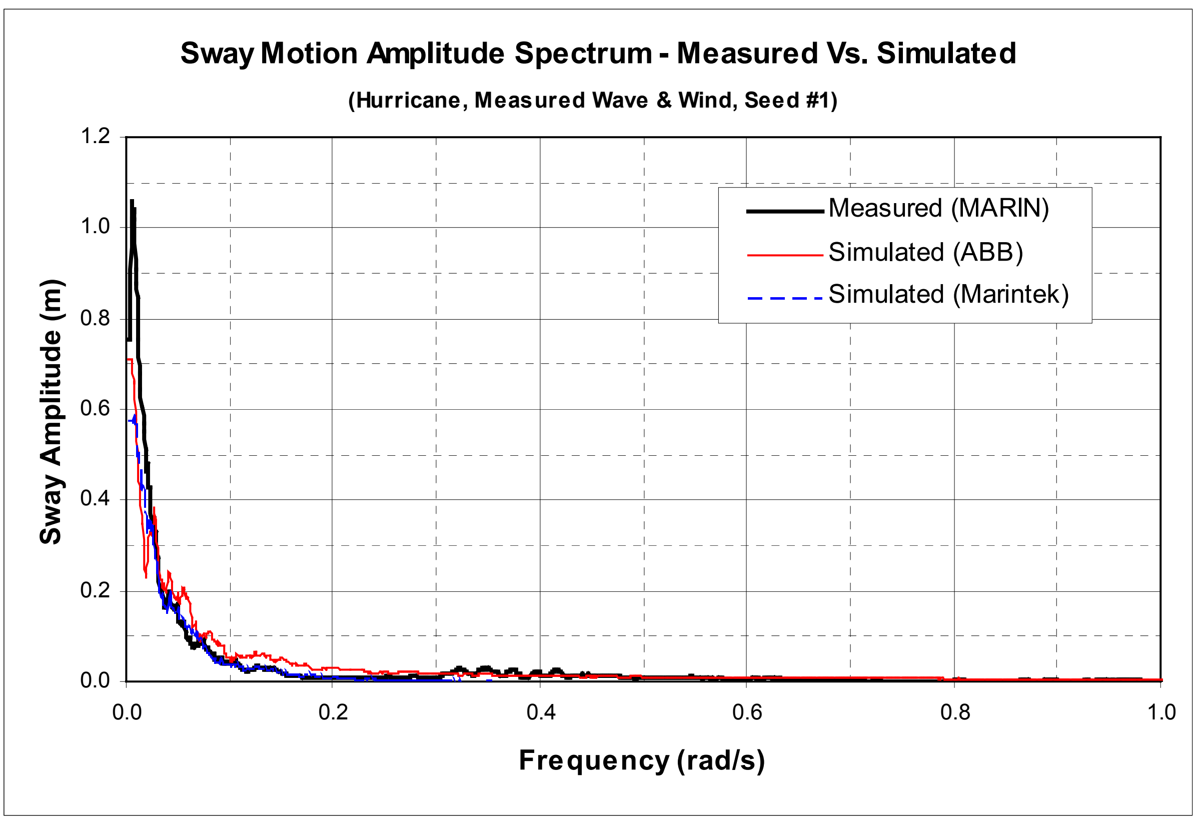

Figure 11

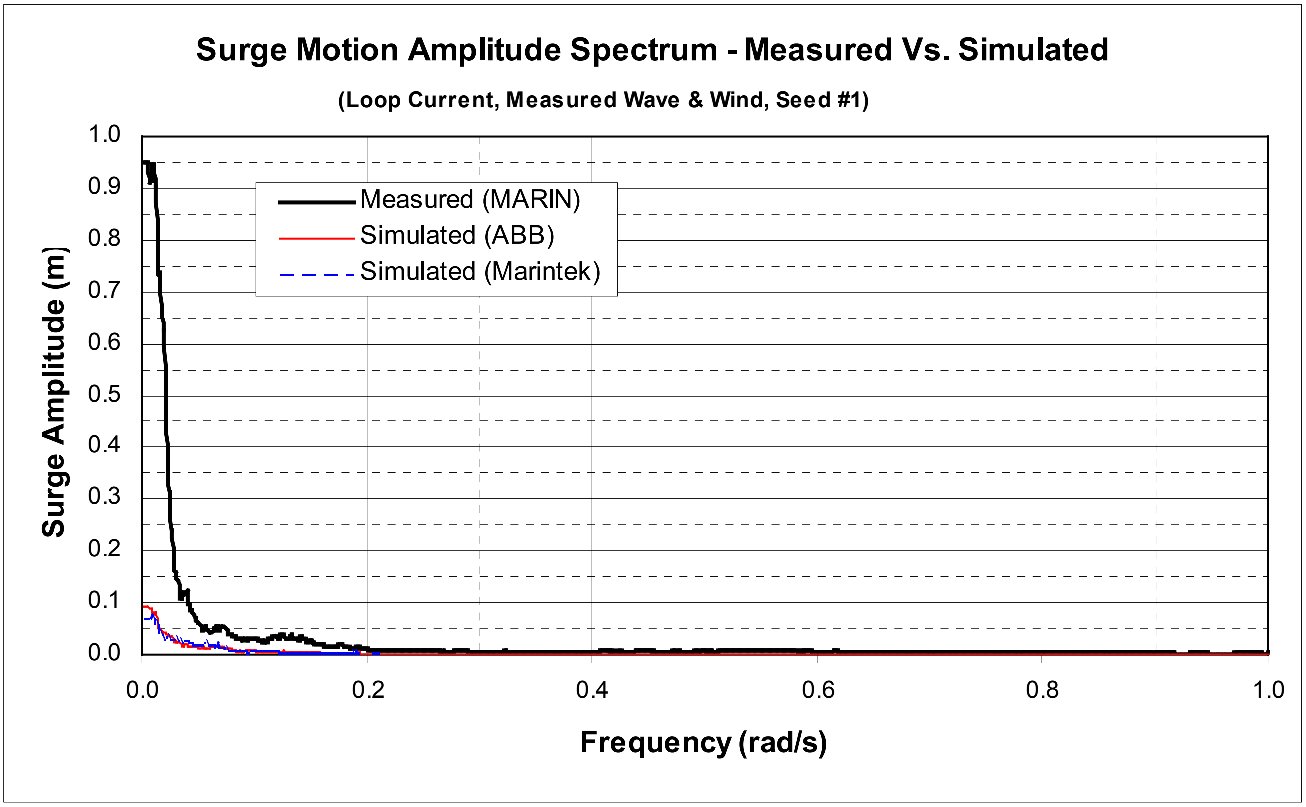

Figure 12

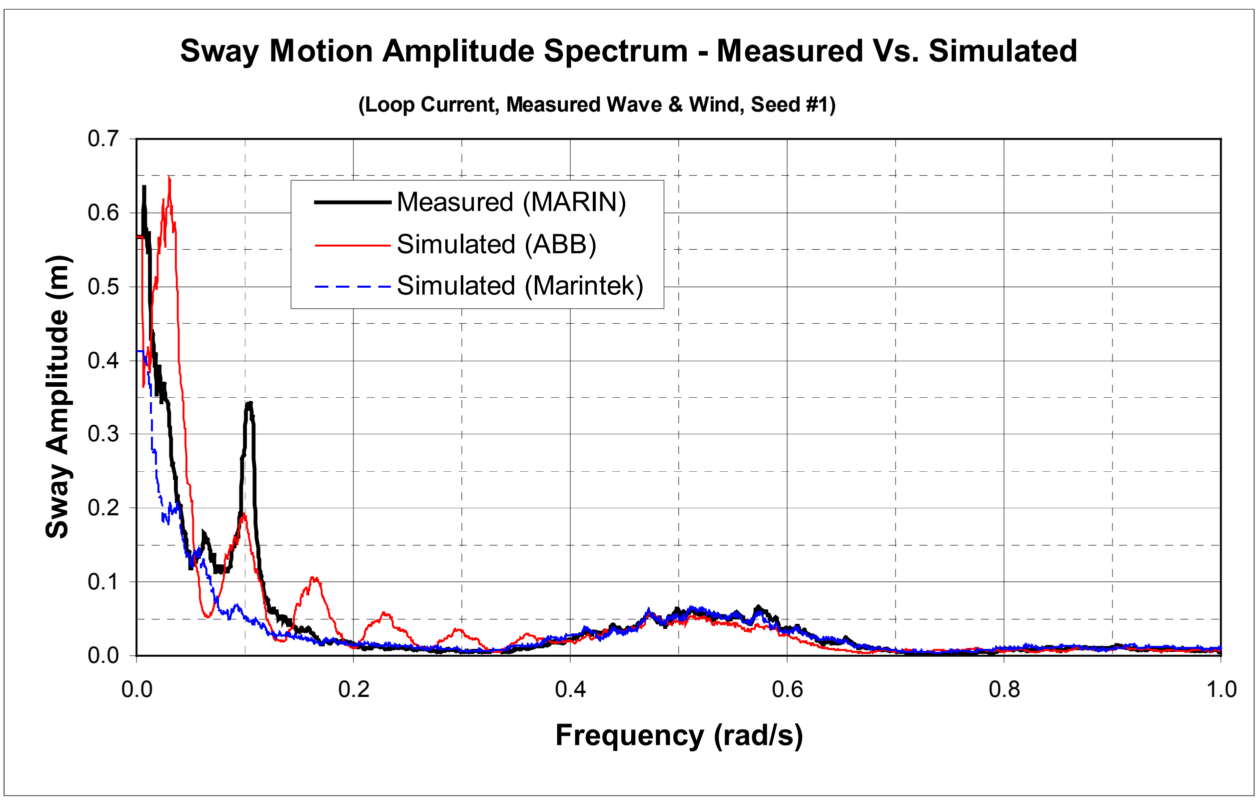

Figure 13

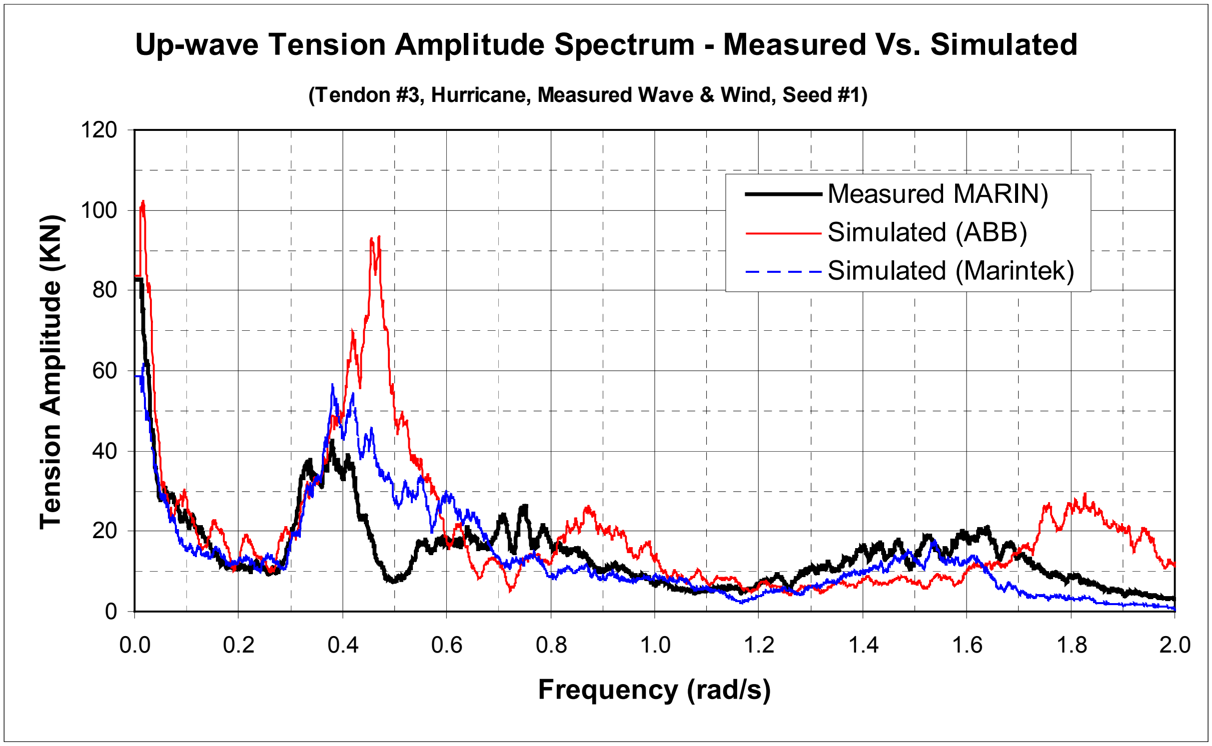

Figure 14

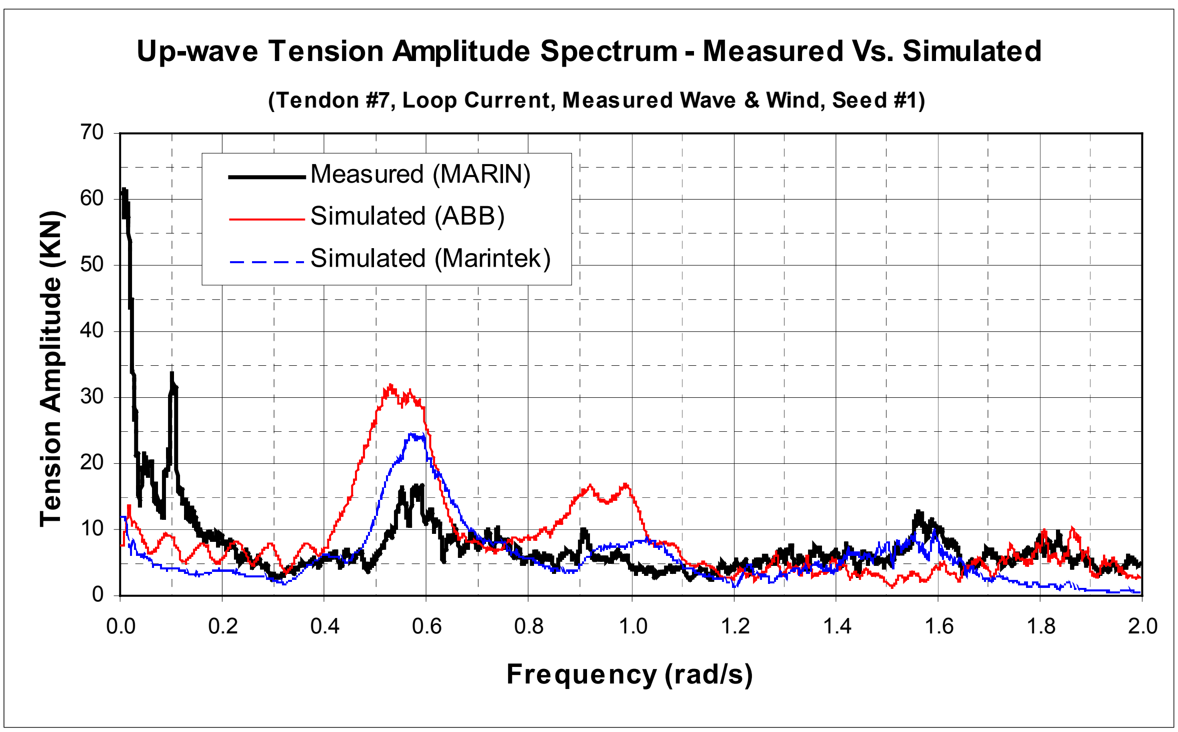

Figure 15

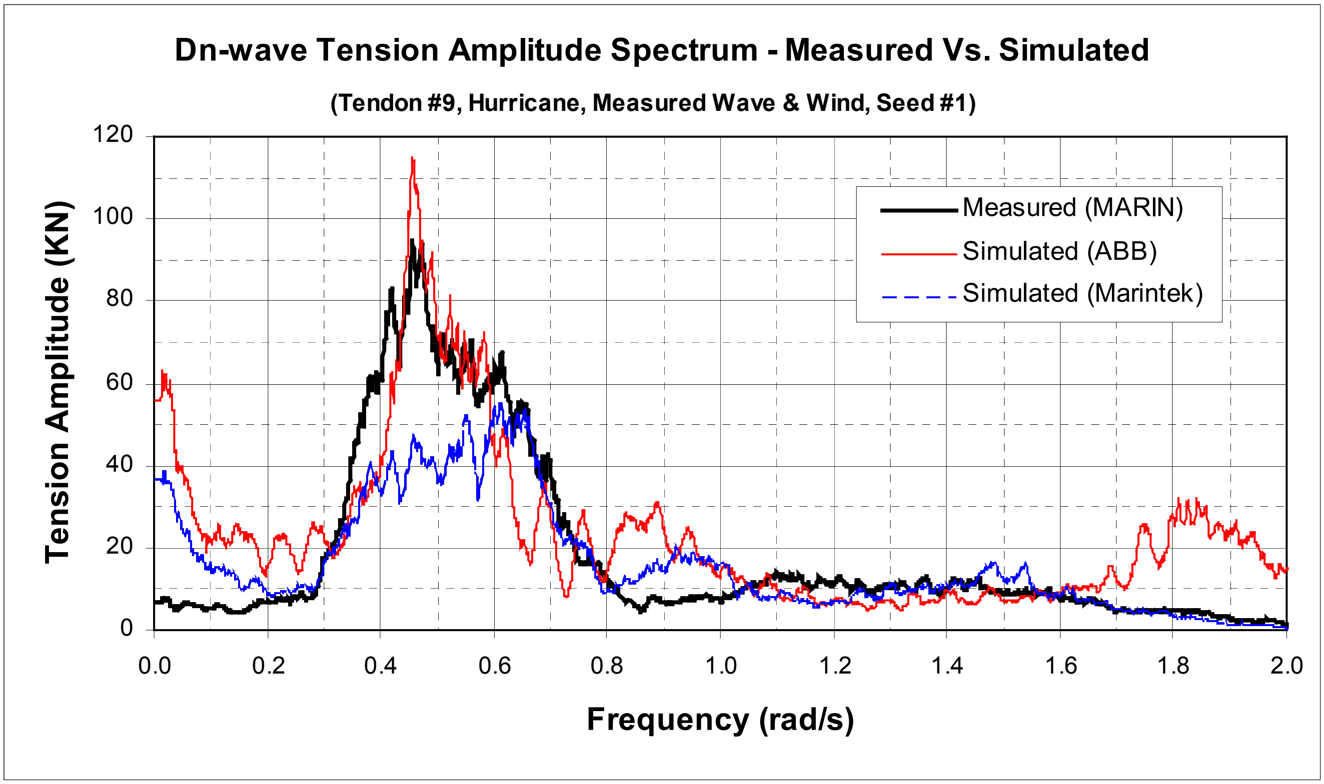

Figure 16

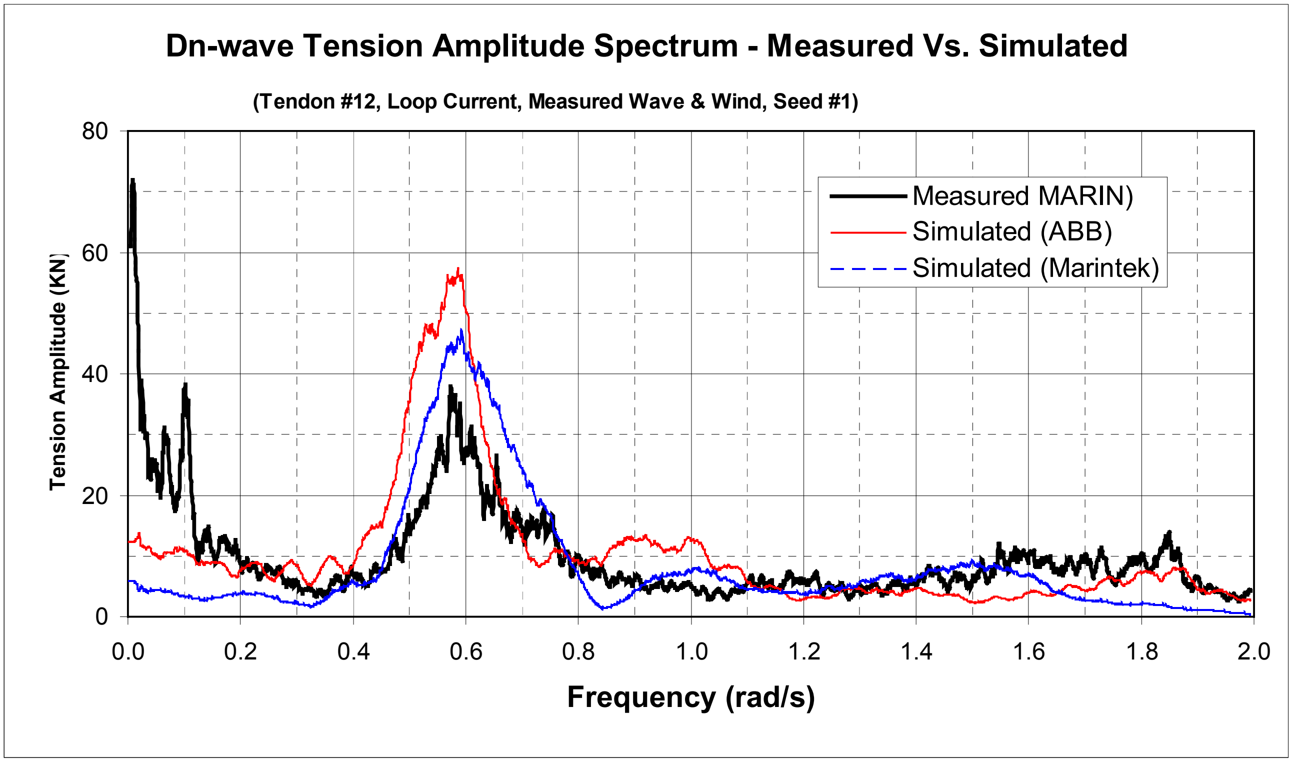

Figure 17

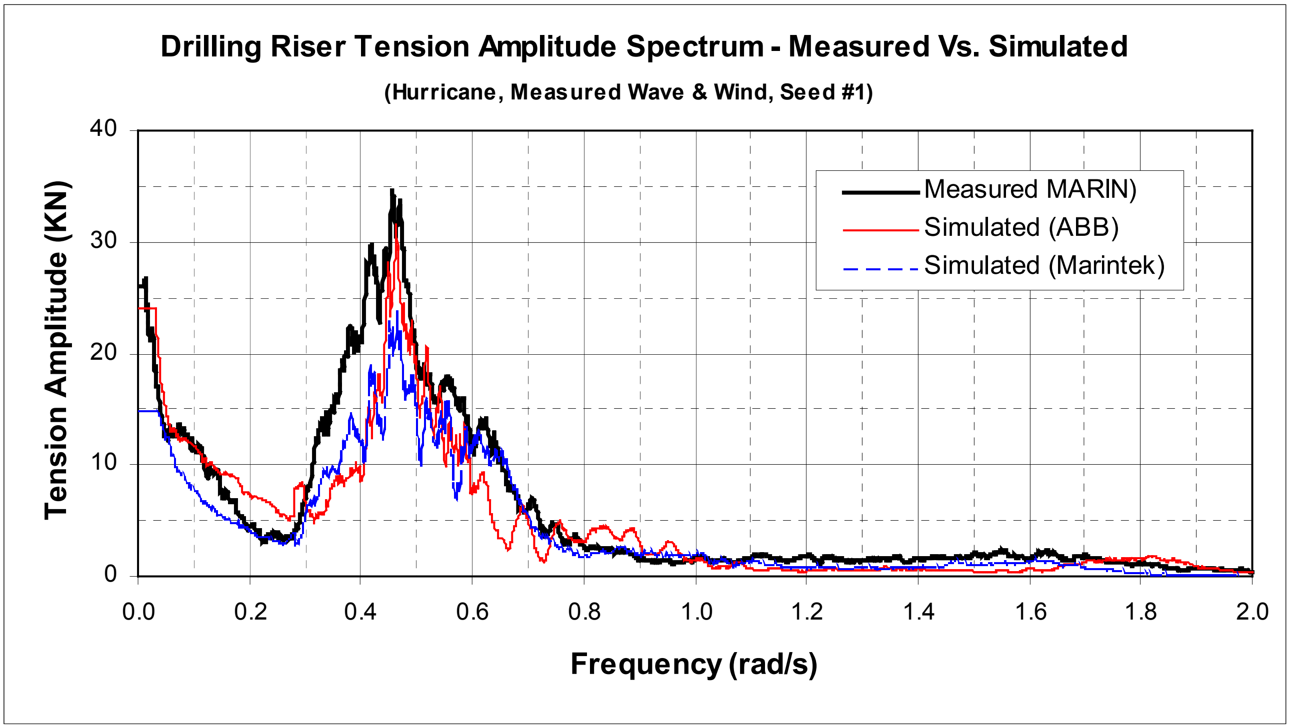

Figure 18

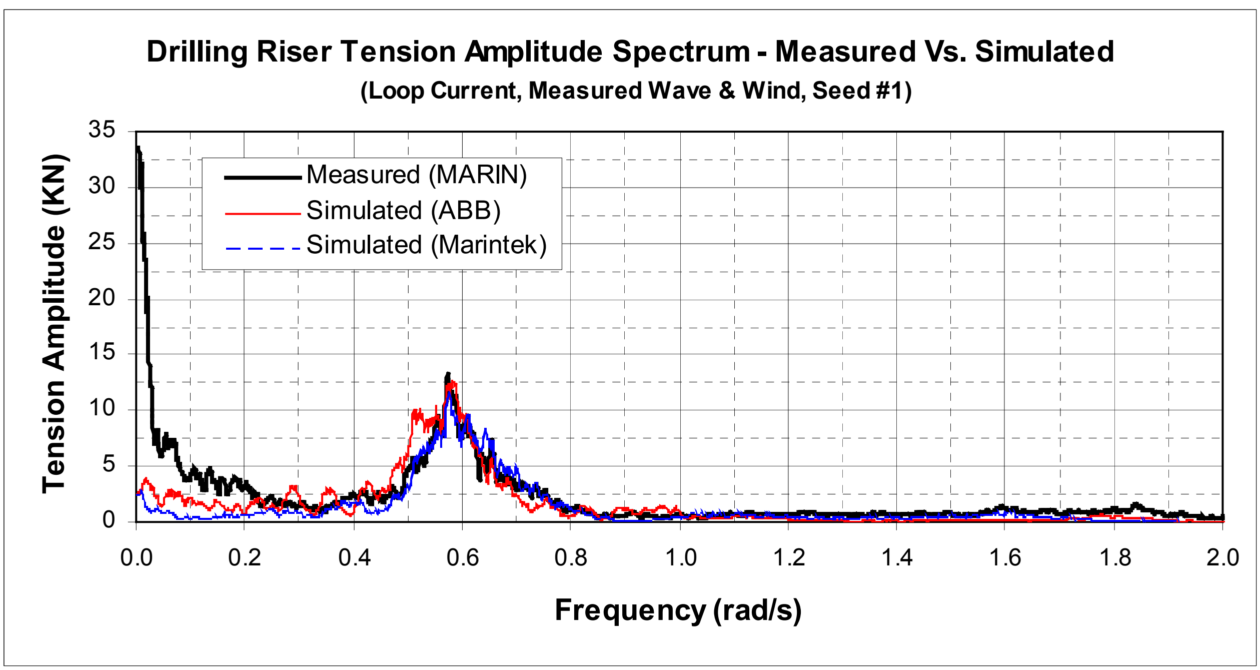

Figure 19

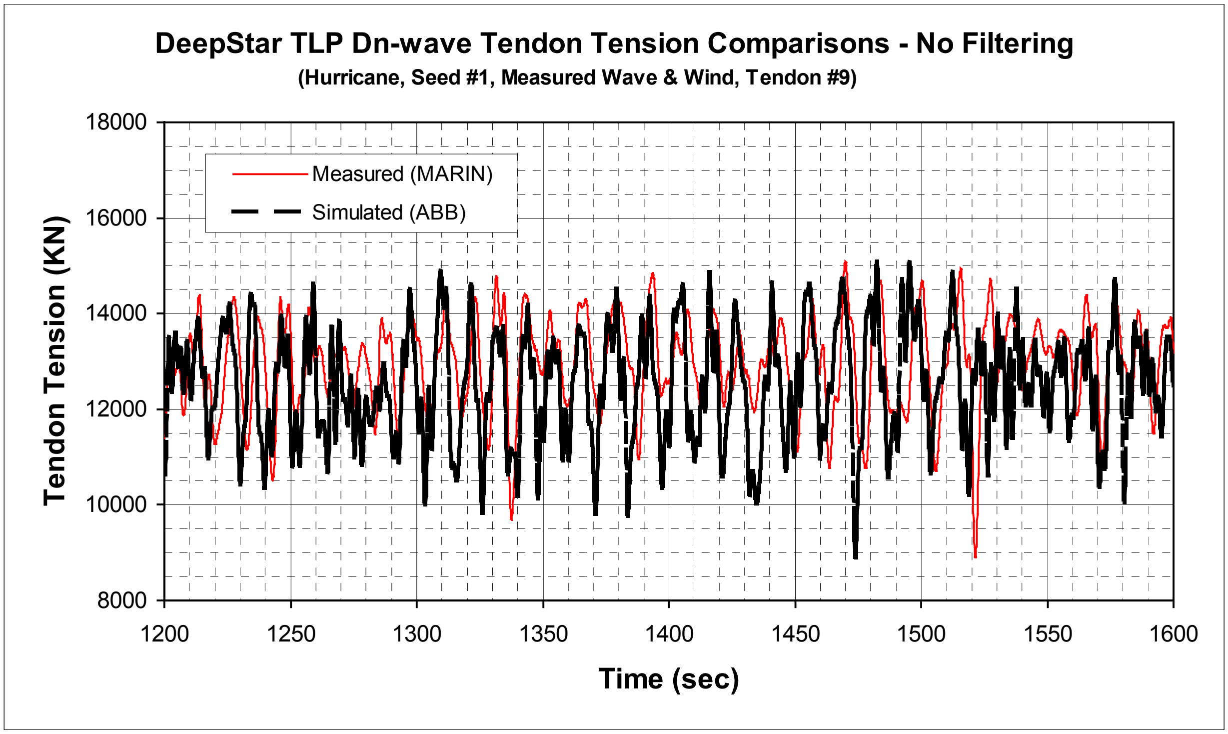

Figure 20

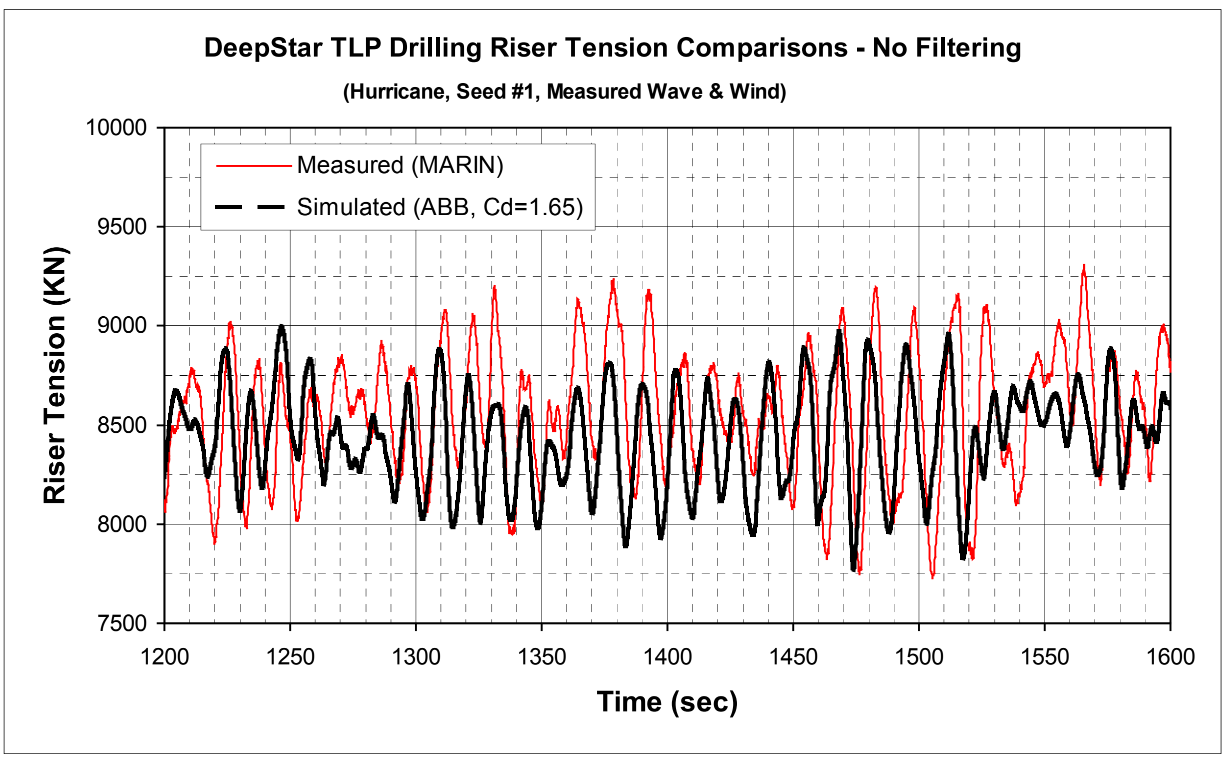

Figure 21